DETAILED ANALYSIS OF SYNOPTIC WEATHER AS OBSERVED FROM PHOTOGRAPHS TAKEN ON TWO ROCKET FLIGHTS OVER WHITE SANDS, NEW MEXICO, JULY 26, 1948

J. Bjerknes
Consultant to the Engineering Division
of The RAND Corporation

P-887

April 1, 1951

Reproduced by

The RAND Corporation • Santa Monica • California

The views expressed in this paper are not necessarily those of the Corporation

CLEARINGHOUSE FOR FEDERAL SCIENTIFIC AND TECHNICAL INFORMATION CFSTI
DOCUMENT MANAGEMENT BRANCH 410 11

LIMITATIONS IN REPRODUCTION QUALITY

ACCESSION #

☐ 1 WE REGRET THAT LEGIBILITY OF THIS DOCUMENT IS IN PART UNSATISFACTORY REPRODUCTION HAS BEEN MADE FROM BEST AVAILABLE COPY

☐ 2 A PORTION OF THE ORIGINAL DOCUMENT CONTAINS FINE DETAIL WHICH MAY MAKE READING OF PHOTOCOPY DIFFICULT

☐ 3 THE ORIGINAL DOCUMENT CONTAINS COLOR BUT DISTRIBUTION COPIES ARE AVAILABLE IN BLACK-AND-WHITE REPRODUCTION ONLY

☐ 4 THE INITIAL DISTRIBUTION COPIES CONTAIN COLOR WHICH WILL BE SHOWN IN BLACK-AND-WHITE WHEN IT IS NECESSARY TO REPRINT

☐ 5 LIMITED SUPPLY ON HAND WHEN EXHAUSTED DOCUMENT WILL BE AVAILABLE IN MICROFICHE ONLY

☐ 6 LIMITED SUPPLY ON HAND WHEN EXHAUSTED DOCUMENT WILL NOT BE AVAILABLE

☐ 7 DOCUMENT IS AVAILABLE IN MICROFICHE ONLY

☐ 8 DOCUMENT AVAILABLE ON LOAN FROM CFSTI (TT DOCUMENTS ONLY).

☐ 9

NBS 9 64 PROCESSOR

NOTE

This paper originally appeared as an appendix to RAND Report R-218, which is classified and therefore not widely available. It is being issued separately at this time, June 1, 1956, at the request of the U. S. Air Force.

DETAILED ANALYSIS OF SYNOPTIC WEATHER AS OBSERVED FROM PHOTOGRAPHS TAKEN ON TWO ROCKET FLIGHTS OVER WHITE SANDS, NEW MEXICO, JULY 26, 1948

By J. Bjerknes

Department of Meteorology, University of California
at Los Angeles

THE FRONTAL CLOUDS

In the composite picture from the highest altitude of V-2 No. 40 (Fig. 1), a strip of flat cloud (actually altostratus and altocumulus) can be seen in the northwest quadrant, extending from the Rio Grande 300 mi west to Flagstaff, Arizona. That cloud strip can be identified as being the remnant cloud of the trailing end of a cold front from the cyclone, north of the Great Lakes in Fig. 2. The outline of the main areas of alto cloud and cirrus cloud as seen from the highest levels of the rocket flights has been entered on the map in this figure.

In the Rio Grande valley, the southern sharp edge of the alto cloud sheet is located near Socorro, New Mexico, while the more irregular northern edge lies about 50 mi farther upriver in the region south of Albuquerque, New Mexico. The front cloud is thin, shows holes and cracks at many places, and does not seem to give any frontal precipitation. Nevertheless, the strip of frontal cloud marks an important air-mass limit between subsident polar air to the north and partly thundery tropical air to the south.

Presumably also of frontal origin are the cirrus clouds, which can be seen to extend in a zone near the Mexican border parallel to the strip of altostratus-altocumulus. The zone of cirrus seems to come to an end over southwestern Arizona.

LEGEND FOR FIG. 1

Composite picture covering the southwest and northwest quadrant, as seen from the V-2 near 60 mi elevation (about 11:05 A.M., MST, July 26, 1948), and another composite picture covering a north-to-south strip from Wyoming to Mexico, as seen from the Aerobee near 70 mi elevation (about 9:50 A.M. MST, same day). Official U.S. Navy-John Hopkins University (APL) photograph.

Identification numbers in the upper composite (V-2) are as follows: (1) Mexico; (2) Gulf of California; (3) Lordsburg, New Mexico; (4) Pelocillo Mountains; (5) Gila River; (6) San Carlos Reservoir; (7) Mogollon Mountains; (8) Black Range; (9) San Mateo Mountains; (10) Magdalena Mountains, (11) Mount Taylor; (12) Albuquerque, New Mexico; (13) Sandia Mountains; (14) Valle Grande Mountains; (15) Rio Grande River; and (16) Sangre De Cristo Range.

Identification numbers in the lower composite (Aerobee) are as follows: (1) Mexico; (2) Texas; (3) Rio Grande River (note that this is indicated in three places); (4) Ciudad Juarez, Mexico; (5) El Paso, Texas; (6) Biggs Field Army Air Base; (7) Franklin Mountains; (8) Southern Pacific railroad, with highway alongside; (9) Organ Mountains; (10) Tularosa Basin; (11) V-2 and Aerobee launching sites; (12) Base Headquarters, White Sands Proving Grounds, New Mexico; (13) San Andres Mountains; (14) White Sands National Monument area; (15) Alamogordo Army Air Field; (16) Alamogordo, New Mexico; (17) Tularosa, New Mexico; (18) Sacramento Mountains; (19) Malpais, or ancient lava beds; (20) test site for the first atomic bomb; (21) Albuquerque, New Mexico; and (22) areas of Wyoming.

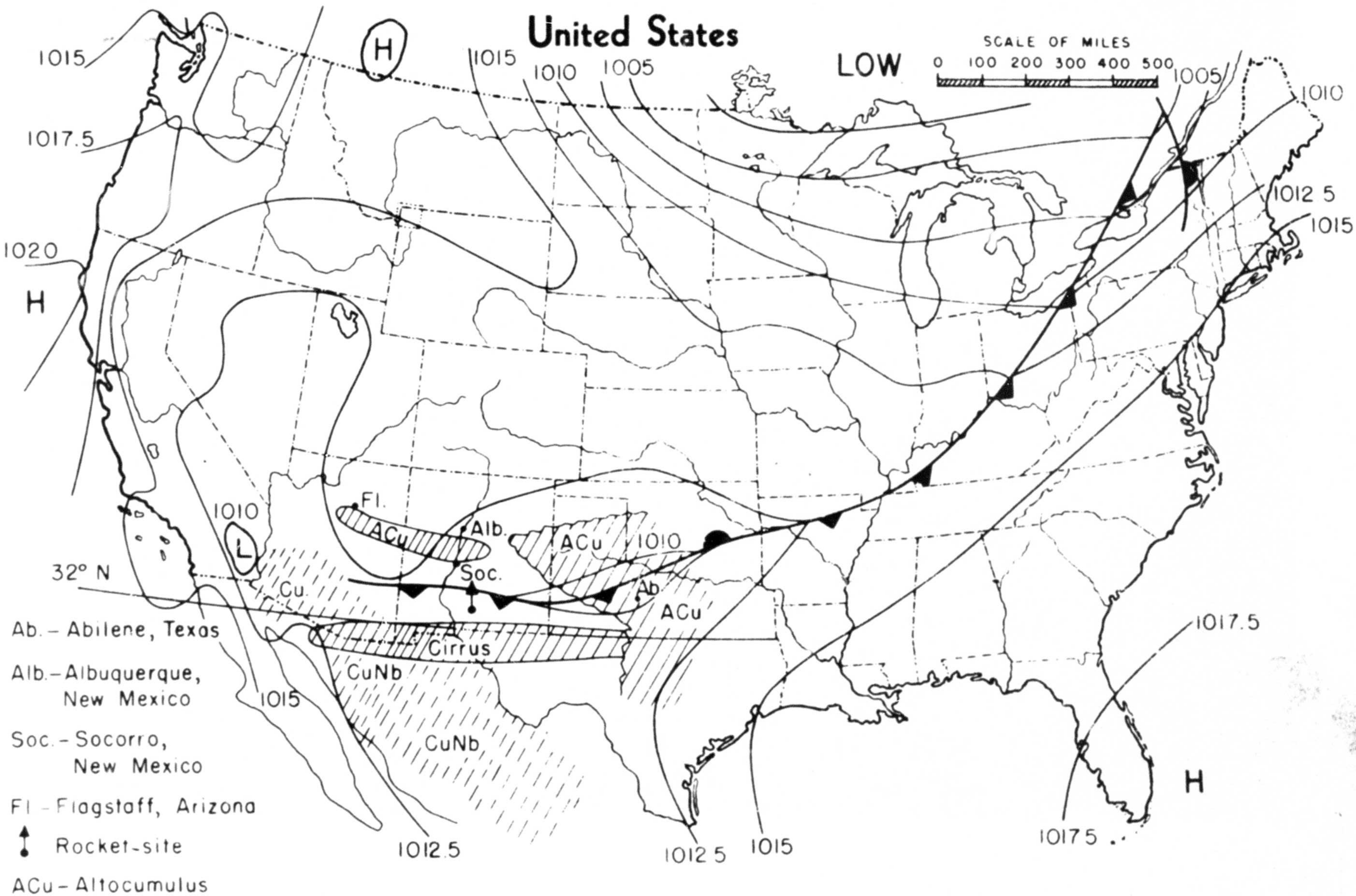

Fig. 2 – Surface Weather Map for July 26, 1948, 1130 MST.

For the reader with access to the complete sequence of pictures taken from the Aerobee (firing time 9:47 A.M., MST) and the V-2 (11:03 A.M., MST) the detailed description of the frontal-cloud cirrus, altocumulus, and alto-stratus on pages 10 through 12 may be useful. The study of the pictures from low altitude in conjunction with those from the higher altitude is a help toward the right interpretation of the unfamiliar look of clouds from 60 to 70 miles elevation.

The distribution of the frontal cloud, viz., altocumulus, altostratus, and cirrus, can be understood from an inspection of the maps of upper winds in Fig. 3. The line of convergence, marking the front, goes through New Mexico on the 14,000-ft map just where the strip of alto cloud is seen on the composite photograph in Fig. 1. While there is a general afflux of tropical air to the line of convergence at 8000 ft, the flow picture is more complicated south of the front at 14,000 ft, owing to the splitting up of the subtropical high into two cells, one over northern Mexico and one over the Mexican Gulf. West of the Mexican high, the tropical air continues to flow toward the front, thus keeping the strip of alto cloud, from Flagstaff, Arizona to the Rio Grande, narrow and well defined. Farther east, the tropical air partly branches off southward around the Mexican high, and what there is available of frontal cloud will be thinning out and spreading over a large area (such as that shown by the northeast-quadrant pictures).

The cirrus zone through southern Arizona and New Mexico lies along a line of convergence between northerly and easterly winds on the 30,000-ft map. This line of convergence at 30,000 ft is not the same as that shown at 14,000 ft between the cold high over Utah and the warm high over northern Mexico.

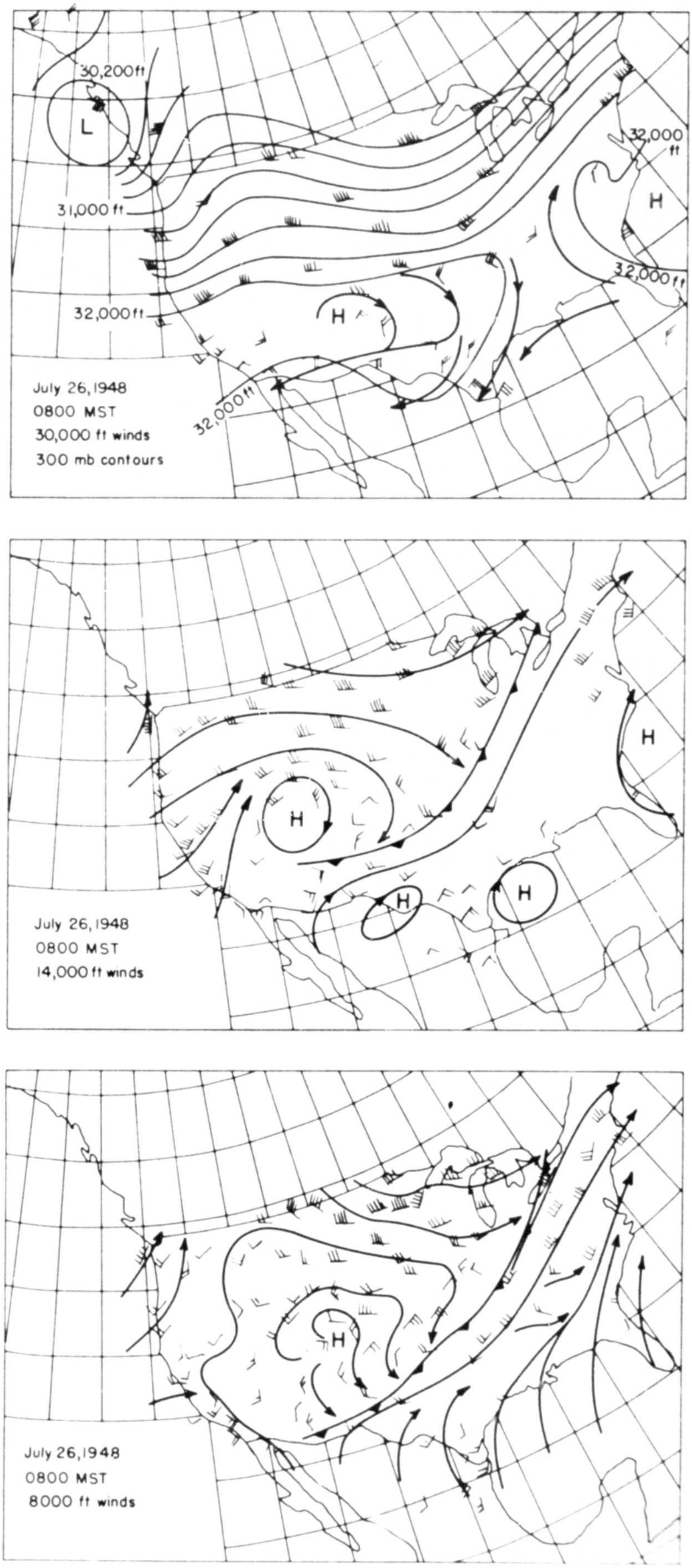

Fig. 3 — Selected Upper-Air Wind Maps.

Already at 18,000 ft (not reproduced), the cold high has disappeared, and farther up the warm high is found to tilt northwestward so as to be centered over northwestern New Mexico at 30,000 ft. The origin of the cirrus probably must be sought over the front a day or two earlier, when it must have had the usual high build-up of cloud typical of rainy fronts. The light northerly winds to the east of the 30,000 ft high-pressure center must have separated the cirrus from the stagnating frontal altocumulus strip over northern New Mexico and herded them into the zone of convergence between northerlies and easterlies at the Mexican border. The westward views therefore show the cirrus and altocumulus in two parallel zones separated by a cloudless space whose width is 150 to 200 miles. The eastward views, on the other hand, cover an area where in the distance the altocumulus is drifting southward as "prefrontal cloud" with about the same forward edge as that of the cirrus.

THE AIR-MASS CLOUDS

The cumuli and cumulonimbi are easy to recognize from any rocket elevation. They form preferably over mountain ranges, whereas the large desert flats remained cloudless at the time of the rocket flights. There is quite a noticeable growth of all cumuliform cloud in the interval between the taking of the Aerobee pictures (9:47 A.M.) and the V-2 pictures (11:03 A.M.). Of particular interest is the different cloud growth in the polar air north of the front and the tropical air to its south and also the different cumuliform activity in the various parts of the tropical air.

The cumuli north of the front are rather flat, even where they feed on the thermal convection over the 14,000 ft peaks of the Rockies north of Durango, Colorado. No anvils are to be seen over the entire area north of the front. South of the front there are several cumulonimbi, and the cumuli show a tendency toward narrow tower formation (most clearly seen in the southwest horizon), which may have led to anvil forms later in the day. The strongest convective activity is seen over Mexico and the western edge of the Arizona plateau from the border to Flagstaff. Scattered thundershowers were reported over that area at 1130 MST and more general thunderstorms at 1730 MST. No cumulonimbi can be seen, and no thunderstorms were reported during the day over the low-lying western part of Arizona and what can be seen of California beyond. New Mexico has towering cumuli and a few cumulonimbi over the mountain ranges close to the front, but the greater part of the state south of the front is cloudless apart from the band of cirrus along the Mexican border (which may hide some cumulus underneath). In the eastern skies, cumulus activity is very sparse. No cumulus heads are seen to pierce the altocumulus level, except

at great distance eastward. That local development can probably be identified with the showers reported at Abilene and Fort Worth, Texas (400 to 500 miles away), later in the day. The southeast quadrant, which is free of altocumulus and cirrus, except for the nearby area, shows only small and scattered cumuli. No showers occurred in that direction during the day.

The great variation of cloudiness and cloud form along a west-to-east profile (Fig. 4) south of the front can be understood as the result of the "cell structure" of the sub-tropical belt of high pressures. Farthest west, the Pacific anticyclone is in its normal position over the ocean; a warm continental anticyclone can be seen in the maps of upper winds from 10,000 ft upward, with its axis tilting from western Texas at 10,000 ft to northwestern New Mexico at 30,000 ft. Finally, a third anticyclone is located in low layers over the Gulf of Mexico. The air of the Pacific anticyclone forms a shallow cold wedge invading the California coastal strip, and the air of the Gulf anticyclone forms a deeper moderately cold wedge covering most of Texas. Between the two cold wedges, the "continental tropical air" of the middle anticyclone occupies widening space with increasing elevation.

The low cloud of the Pacific anticylone is known to be only of stratus type. Above the stratus, the air is kept very dry through sinking. The air of the western end of the Gulf anticyclone lies in a wedge shape under that of the warm continental anticyclone. The sloping boundary surface between the two air masses (both tropical) is at the same time characterized by the change from southerly winds below to northerly winds above. That feature in the wind field is found at 14,000 ft at the Texas coast and tilts down toward 8000 ft in the region of the highlands of western Texas and northern Mexico. The air space below that tilting surface of discontinuity is above freezing temperature, so that even at the Texas coast no complete anvil-capped shower clouds can form.

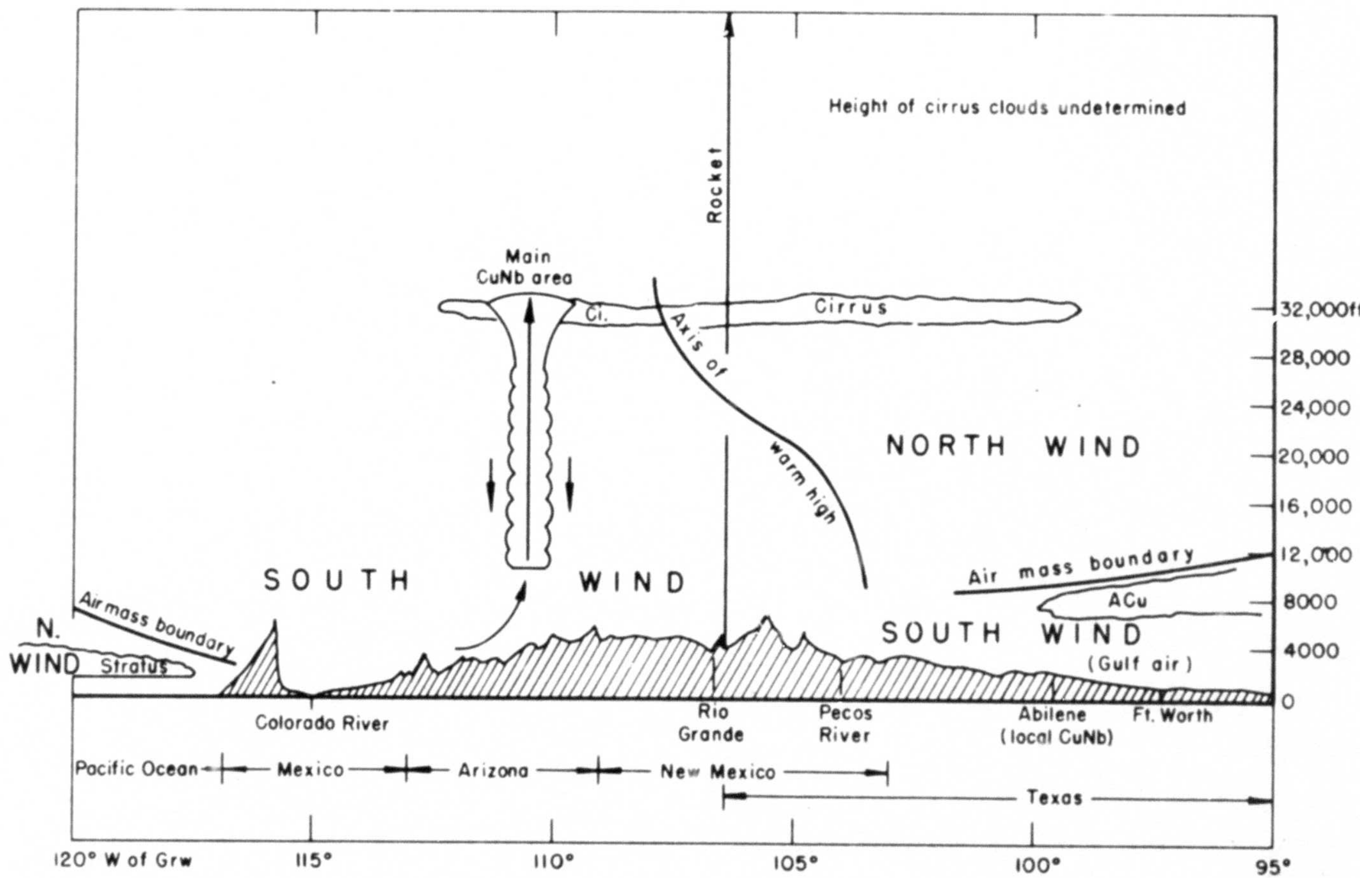

Fig. 4 – Profile along 32° N.

Looking toward the Gulf anticyclone from the rocket (to the right of the eastward cirrus on the pictures) very few cumuli are seen, and they are all of moderate size, as can be expected from Fig. 4.

The middle anticyclone cell in Fig. 4, being warmer than those to the west and east, occupies widening space with height, and the cumulus towers in that space are not hindered in their growth by air-mass boundaries. All the high-reaching cumuliform clouds seen from the rocket belong to that warmest subtropical cell of high pressure. The greatest density of cumuliform cloud is observed over the northern Mexican highlands where moist tropical air from the south is injected below the level at which the warm anticyclone begins to appear (see the 8000-ft map in Fig. 3). From that main region of cumulus activity, a narrow branch of high-reaching cumuliform cloud extends along the mountain ranges at the western edge of the Sonora and Arizona high plateau (a favorable region for convection, because of slope circulations between the western low lands and the high plateau). Farther east, inside the same anti-cyclone (southern New Mexico), the cumulus activity is weak or absent. This is probably owing to the fact that the lower levels have been invaded by polar air (see the 8000-ft map, Fig. 3).

Right along the frontal strip of alto cloud from Flagstaff to the Rio Grande, the convective activity is favored and breaks through the alto level to form anvil tops. The more diffuse continuation of the front east of the Rio Grande is not associated with any cumulonimbus formation for several hundred miles. The distant cumulonimbus formation toward Abilene, Texas, is probably at the front or just to the south of it. The converging flow at 8000 ft (Fig. 3) in that region seems to justify the cumulonimbus formation there.

The tilt of cumuli can be seen to indicate an increase of westerlies with height in the polar air toward the far northern edge of the cloud panorama. The shape of the cumuli closer to the north side of the front indicates very light winds and little change of wind with height. South of the front, the cumuli drift from the west and dissolve downwind from the mountain ranges over which they were formed. The tilt of the Arizona cumulonimbi shows a slight increase of southerlies with height, and the anvils of the cumulonimbi over Mexico, due south of the rocket, show increasing easterlies with height. These wind shears observed through cloud tilts would indicate temperature decrease both northward, westward, and southward from the rocket side. This is corroborated by the radiosonde temperatures in the middle and upper troposphere measured in the morning and in the evening of the launching day. Actually, the launching took place in a warm upper anticyclone, Big Springs, Texas, being the warmest place at 300 mb with a $-27^{\circ}C$. From the center of the upper warm high, the cumulonimbi in all directions should be seen to tilt toward the right. The distant cumulonimbi due east do not reveal any definite tilt, but apparently they are located only a very little east of the warmest point.

SUMMARY

~~In summary, it may be said that the~~ rocket pictures add a considerable amount of interesting information to the ordinary weather-map analysis, and in addition, that the accumulated knowledge from the maps helps ~~us~~ in the new problem of interpreting what ~~we see~~ from high-level rocket pictures. The question as to how much of the synoptic picture can be derived from the rocket photographs alone has been treated in the main body of the report.* It may be added that although in the present paper the ordinary surface and upper-wind maps had to be used to a great extent to arrive at the total picture, accumulated experience from several analyses by joint rocket and conventional methods would make it possible to arrive at the right analysis by rocket pictures only.

The rocket pictures will certainly show all fronts quite well. The front discussed in this paper was a very weak one, but its existence is clearly revealed by the "frontal arrangement" of alto and cirrus clouds over several hundred miles. Repeated pictures at 24-hr intervals or less over wide areas would in most cases establish the continuity in time and space of each front almost as well as is done by consecutive weather maps. Some difficulties may be anticipated when the background for the upper cloud is not so dark as that provided by the earth. If the ground is covered with new snow, fog, or uniform low sheet clouds (stratus), it may at times be difficult to discern the pattern of medium and upper cloud against the background of equal whiteness. However, it can be expected that this white background will never be entirely devoid of a structure pattern of its own which would present some contrast to the upper cloud. Moreover, the shadow of upper cloud thrown upon the lower cloud would certainly help to give a stereoscopic view of the frontal cloud systems.

---

*This information has since been published in S. M. Greenfield, Synoptic Weather Observation from Extreme Altitude, The RAND Corporation, Paper P-761, February 15, 1956 (Unclassified).

The wind direction at ground level would be well shown by the smoke from cities or from isolated big factories. The wind at the cumulus level can be observed clearly over hilly country, where the hills are source regions for trails of downwind cumuli. Over entirely flat country, that type of wind observation might fail; but the tilt of individual cumuli would show the direction of the shear of the wind which in low levels would show the direction of the wind itself after correction with the known relationships between wind and wind shear in the friction layer. Where there are cumulonimbi, the wind-shear observations are available up to about 30,000 ft, and these give the very useful indication of the direction of the horizontal temperature gradient (90° to the left of the wind-shear vector in the northern hemisphere). In the usual middle-latitude pictures, the wind shears would be much stronger and easier to observe than in the case considered in this paper and would mainly point out the normal tropospheric decrease of temperature poleward. Deviations from that due-northward direction of the horizontal temperature gradient would show the location of cold and warm tongues, which is one important feature of the three-dimensional synoptic picture.

The everlasting shortcoming of the synoptic analysis by rocket pictures alone lies in the fact that no quantitative picture of the pressure field is obtained. Only indirect, and very uncertain, guesses can be made regarding the depth of low-pressure centers and the change with height of the horizontal pressure gradient (from the wind shears). But even in this problem, accumulated experience might help. The observable change from an open-front wave to an occluded vortex (in a time succession of pictures) would tell about the intensification of the corresponding low-pressure center and its growth up to the higher layers. Or, as another example, the "steering" of a small

cyclone by the circulation system of a larger one may be synthesized from a coverage of pictures in time and space. The implication concerning the pressure field should then be that the cyclone providing the center of steering must be a cold-core one having a greater depth of its pressure center in higher layers, whereas the steered cyclone should be a warm-core shallow one having a moderate present pressure minimum with potentialities for deepening.

A detailed description of the cirrus and the alto cloud as seen on Aerobee pictures (9:47 A.M., MST) and V-2 pictures (11:03 A.M., MST) is as follows:

CIRRUS CLOUDS - SEEN FROM VARIOUS ELEVATIONS

A good view of the cirrus from below is afforded by the Aerobee pictures 3, 4, and 5 (westward), 10 and 11 (eastward), 12 and 13 (southward), and 14, 15, and 16 (westward). There is no cirrus in the northern sky. The next eastward views in 21 and southeastward in 22 show patches of altocumulus under the rocket level, the cirrus still being above. The following pictures, 23 through 27, show the traversing of the cirrus level in views changing slowly from southwest to west-northwest. The cirrus has a flat top. Pictures 28 through 34 (northwestward) show some small patches of distant cirrus imbedded in haze. With a temporary rocket spin opposite to that observed in the beginning of the flight, pictures 36 through 40 give westward views of nearby dense cirrus seen from above. Next, the views change back from west past north to east, where the eastward part of the cirrus zone is now seen from above in pictures 46 through 58. The haze horizon, which presumably marks the tropopause, is still well above the cirrus. In

pictures 59 and 60, the next southeastward views toward the sun, the haze horizon is sharp and probably not far from the level of the rocket. The eastward and nearby part of the cirrus zone can also be seen in pictures 72, 73, 74, 86, 99, 100, 113, 114, 127, 128, 141, 142, 143, 156, 157, 170, 171, 184, 185, 198, 199, 212, 213, 230, 231, and 232, but no westward view is available because of the orientation of the rocket.

In the V-2 pictures, the cirrus begins to appear on picture 20 at the left edge of the west-northwest oriented view. Pictures 35, 36, and 37 are oriented more due west and show more of the cirrus, still extending from the left edge. The following pictures turn more northward, away from the cirrus. In 56 through 60, the cirrus zone to the eastward is seen, already below the rocket level. In 91 through 94, a corresponding view of the westward part of the cirrus zone is seen, very much like the composite view from the maximum altitude. The nearby and distant parts of the western cirrus are seen again in 117 through 121, 146 through 149, 174 through 178, and 201 through 208, and the eastern cirrus is seen in 215 through 219 and 227, 228, and 229 (end of film).

There is a noticeable difference in the apparent whiteness of the eastward and westward cirrus when seen from above. With the sun in the southeastern quadrant, the cirrus in the east offers a better light reflection than that in the west. The cirrus toward the sun is as white as the water clouds (altocumulus and cumulus) below, whereas the cirrus in the west appears greyish in comparison.

ALTOCUMULUS AND ALTOSTRATUS - SEEN FROM VARIOUS ELEVATIONS

In the Aerobee pictures looking northward across White Sands, the frontal strip of altocumulus can be faintly seen through the haze in pictures 8, 18, and 19. In 21 and 22 there are nearby patches of altocumulus below the rocket. In the northwestward views of 30 through 35, some distant patchy altocumulus is seen, which must belong to the front. The same appears more clearly in 41 through 44. East of the Rio Grande, in 44 and 45 the altocumulus is also found, but in small patchy sheets. In the east-northeast view in 46, altocumulus sheets are seen in the distant left and cirrus in the near right. The same sweep along the frontal altocumulus from west past north to east-northeast is seen in 53 through 58, 66 through 72, and 80 through 85. With increasing height of the rocket, extensive distant sheets of altocumulus appear toward the east and northeast (85), at one place toward the east pierced by cumulus heads. The higher pictures from the Aerobee add nothing essential to the above survey of alto clouds.

The first frontal alto cloud in the V-2 pictures becomes visible behind the cumulus of the Black Range on picture 30 but disappears, owing to the turn of the rocket after 36. They reappear on 38, where a cumulonimbus is also seen to pierce the flat sheet of altocumulus at the right edge of the photograph. The same cumulonimbus is seen in 48 and 49. The altocumulus now extends across the Rio Grande, where it had a break in the Aerobee pictures 5/4 hr before. The continuous altocumulus belt now ends 50 miles east of the Rio Grande,

and toward the northeast only distant altocumulus can be seen. The northeastward view from higher levels, in pictures 79, 80, 129, 130, 158 through 160, 186, 187, 188, and 225 through 228, shows widely scattered altocumulus but in less amount than on the Aerobee pictures. The cumulus head piercing the altocumulus on Aerobee picture 85 has developed a large anvil (center of V-2 picture 226).

In contrast to the unorganized, widely scattered altocumulus in the north-east quadrant, there is an orderly arrangement of altocumulus and altostratus in the northwest quadrant long that part of the front extending west of the Rio Grande.